Available online at www.sciencedirect.com

ScienceDirect

Procedia Earth and Planetary Science 15 (2015) 421 – 427

Procedia
Earth and Planetary Science

World Multidisciplinary Earth Sciences Symposium, WMESS 2015

Investigation of Dynamic and Kinematic Landslide Processes By Borehole Tiltmeters and Extensometers

Gyula Mentes[a]*

[a]*Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, Csatkai E. u. 6-8., H-9400 Sopron, Hungary*

Abstract

Landslides cause many damages both in properties and in human life. The high loess banks along the River Danube are the most susceptible areas to mass movements in Hungary. Two test sites, one in Dunaföldvár and the other in Dunaszekcső, were chosen for the investigation of the kinematic and dynamic processes of the high loess banks due to tectonic, hydrologic and environmental effects. On both test sites, more landslides occurred in the last century. In Dunaszekcső the latest landslide took place in 2008. Here a new landslide has been developing since 2010. In Dunaföldvár borehole tilt and borehole extensometric measurements have been carried out since 2002. In Dunaszekcső the borehole measurements began in the autumn of 2007, thus both the large landslide formed in 2008 and the newly developing landslide could be observed. Comparison of tilt data with ground water level changes and the stage of the River Danube resulted in new knowledge of the landslide development processes of the high loess banks. The measurements made evident that the ground water level changes have two-three orders of magnitude larger effect on the high bank stability than the water level variations of the River Danube. The characteristic tilt processes during a 3-4 weeks period before the slump can be used for early warning of landslides. The increasing tilt amplitudes and regression coefficients between tilt and ground water levels could be the precursor of a forthcoming landslide.

Peer-review under responsibilty of the Organizing Commitee of WMESS 2015.

Keywords: Borehole extensometer; ground water; landslide; tilt; water level of the River Danube;

1. Introduction

For landslides damages prediction important is development of early warning systems (EWS), which can play an important role in mitigation of damages. The observation of landslide movements together with geophysical,

* Corresponding author. Tel.: +36 99 508-348.
E-mail address: mentes@ggki.hu

Peer-review under responsibilty of the Organizing Commitee of WMESS 2015.
doi:10.1016/j.proeps.2015.08.025

hydrological and environmental parameters helps to reveal the relationships between movements and the different parameters and it is indispensably necessary to the development of early warning systems. In contrast with the intermittent geodetic measurements (GPS, EDM, precise levelling) the continuously-recording, highly-sensitive borehole tiltmeters and extensometers are especially suitable for the investigations of these relationships (Kümpel et al., 2001; Fabian et al., 2003; Mentes, 2003, 2004). Hydrological processes play a very important role in development of landslides (e.g. Casagli et al., 1999; Rinaldi et al., 2004; Simon et al., 2000; Terlien, 1997), so understanding their role in determining high bank stability is an important research task. Two test sites, one in Dunaföldvár and the other in Dunaszekcső, were chosen for the investigation of the relationships between high bank tilts and hydrologic and environmental effects. In this paper the results of the investigations are described.

2. Test sites

The locations of the test sites are shown in Fig. 1. On both test sites more landslides occurred in the last century. In Dunaszekcső the latest landslide was on 12 February 2008. The height of the high loess wall is about 70 m above the average water level of the River Danube. In Dunaföldvár the height of the loess wall at the test site is 20-30 m. The Digital Terrain Model (DTM) of the test sites is shown in Fig. 1. The test sites are described by Mentes et al. (2009) and Újvári at al. (2009) in detail.

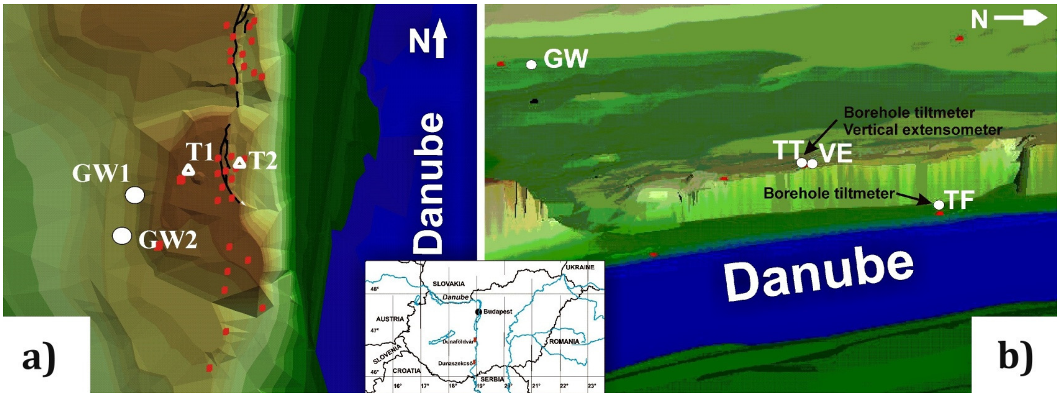

Fig. 1. Digital Terrain Model (DTM) of the Dunaszekcső (a) and Dunaföldvár (b) test site in Hungary. GW, GW1, GW2 denote the position of the ground water level semsors. T1 is the tiltmeter on the stable and T2 is the tiltmeter on the unstable part of the Dunaszekcső high bank. TT is the tiltmeter on the top and TF at the toe of the Dunaföldvár high bank. VE shows the position of the vertical extensometer.

3. Methodology

For continuous monitoring the movements of the high banks two borehole tiltmeters, Model 722A made by Applied Geomechanics Inc. (1991) were installed on the test sites. These tiltmeters have a dual-axis tilt and a built-in temperature sensor. This latter served for instrument and soil temperature measurement in the borehole. The resolution of the tilt and temperature sensors is 0.1 µrad and 0.1 °C, respectively. The tiltmeters were installed in 3 m deep boreholes. In Dunaszekcső one tiltmeter (T1) was installed on the stable and the other instrument (T2) on the unstable part of the high loess bank (Fig. 1a). The instruments are oriented so that their +x axes point to the east and their +y axes to the north. Tilt measurements have been carried out since October 2007. Two water level gauges were installed at locations GW1 (in October 2009) and GW2 (in March 2010). GW1 is located ca. 100 m west of the unstable block, while GW2 is approximately 200 m south of GW1 at a slightly lower height (Fig. 1a).
In Dunaföldvár one tiltmeter was located on the top (TT) and the other at the foot (TF) of the high bank (Fig. 1b) in 2002. This latter tiltmeter is about 50 m far from the River Danube and is functioning below the ground water level, but this circumstance does not influence its stability (Mentes, 2004). The $+y$ component of the tiltmeters was directed to east and so the $+x$ component shows to south. In 2005 a sensitive borehole wire extensometer (VE) was installed on the top of the high wall, close to the tiltmeter TT. The length of the extensometer is 3 m and it is able to measure vertical distance variations in a range of 0–4 mm with a resolution of better than 1 µm (Mentes, 2012).

In 2010 a ground water level sensor (GW) was installed in a well about 500 m far from the high wall (Fig.1b).
On both test sites, the air temperature was measured at the ground surface on the top of the high bank. The tilt, extensometric, temperature and ground water level data were collected with a sampling rate of 1 sample/hour. Daily averages water level data (DWL) of the River Danube have been downloaded from the publicly available website of the Directorate of Water Management (www.vizugy.hu).
Tiltmeter and extensometer data were correlated with the ground water and river water level data. Multivariable Regression analysis (MVR) was carried out between tilt, extensometric data and the hydrologic data to investigate the effect of the water level variations on the high bank movements.

4. Results and discussions

4.1. Movements of the high bank in Dunaföldvár

Tilt measurements in Dunaföldvár from 2002 to 2008 had been evaluated by Mentes et al. (2009). The resultant long-term tilt of the high bank calculated from the data recorded from 1 Jun 2002 to 31 July 2014 is 140 μrad towards the south-east. Figure 2 shows the data measured from 1 January 2011 to 1 September 2014 since from 1 January 2011 the ground water level was also recorded.
The correlation coefficients between tilt, vertical extension and water levels are given in Table 1. The correlation coefficients are small. The increasing water levels cause the vertical contraction of the high bank due to the increased pore pressure at the bottom of the high bank (negative correlation). To get a quantitative insight into the effect of the water levels and temperature on the tilt the results of the MVR are also given in Table 1. The effect of the ground water level variation is more than three orders of magnitude greater than that of the River Danube. For example, a ground water level rise of one metre causes an eastward tilt of 24.61 μrad of the high bank while one metre of the water level rise of the River Danube causes only 0.01 μrad tilt. The effect of the air temperature variation is also notable.

Table 1. Correlation and regression coefficients between tilt, vertical displacement (VE) data and the water level of the River Danube (DWL), the ground water level (GW) and the air temperature (T).

Tilt components and vertical ext.	Correlation coefficients			Regression coefficients		
	DWL	GW	T	DWL	GW	T
TTS	-0.23	-0.29	0.51	-0.09 μrad m^{-1}	-28.19 μrad m^{-1}	9.91 μrad K^{-1}
TTE	0.02	0.22	0.17	0.01 μrad m^{-1}	24.61 μrad m^{-1}	3.90 μrad K^{-1}
TFS	-0.01	0.58	0.25	-0.00 μrad m^{-1}	38.77 μrad m^{-1}	3.27 μrad K^{-1}
TFE	0.33	0.11	-0.46	0.12 μrad m^{-1}	9.15 μrad m^{-1}	-7.65 μrad K^{-1}
VE	-0.25	-0.91	0.71	-0.00 mm m^{-1}	-0.21 mm m^{-1}	0.03 mm K^{-1}

Symbols means: TTS, TTE and TFS, TFE denote the south and east tilt components on the top and at the foot of the high bank, respectively. Plus sign denote tilts in the south and east, negative sign in the north and west directions. Plus sign of the vertical extension means dilatation.

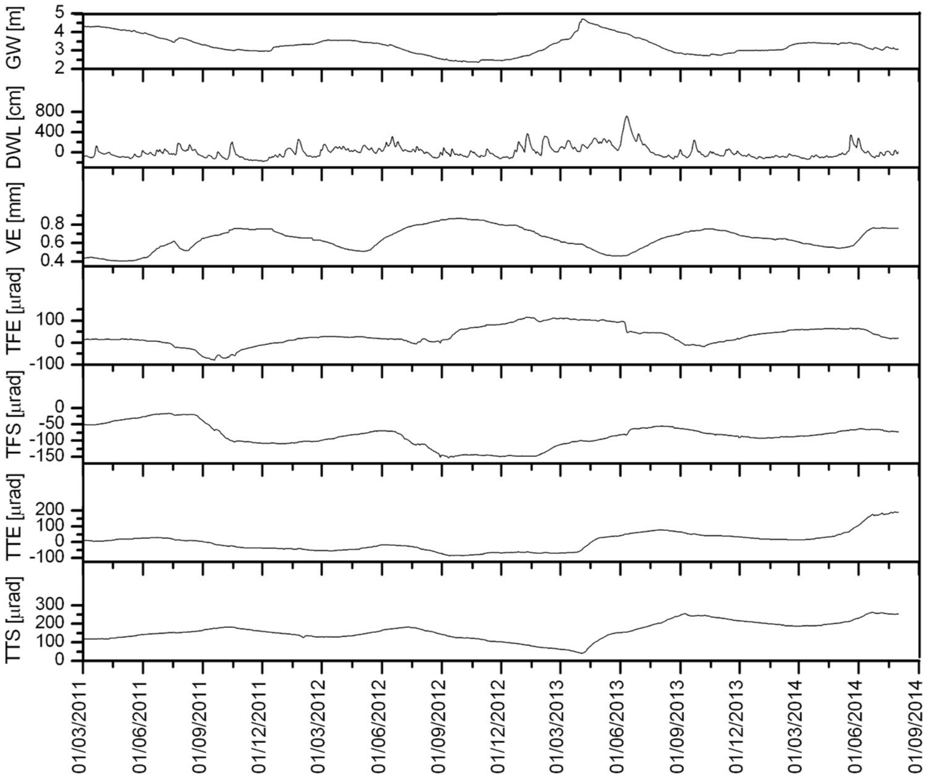

Fig. 2. Data recorded in Dunaföldvár from 1 March 2011 to 1 September 2014. TTS, TTE and TFS, TFE denote the south and east tilt components on the top and at the foot of the high bank, respectively. Tilts going in the positive direction mean tilts in the south and east direction and inversely. VE denote the vertical extension measured by the borehole tiltmeter. The curve going in the positive direction means extension. DWL and GW denote the water level variation of the River Danube and ground water level, respectively.

4.2. Movements of the high bank in Dunaszekcső

The movements of the Dunaszekcső high bank was studied by Újvári et al. (2009) and Bányai et al. (2014) on the basis of geodetic (GPS, precise levelling and EDM) measurements. Since in 2010 a new rupture appeared on the high bank here the data recorded between 1 January 2011 and 19 May 2015 are shown in Fig. 3. In 2014 the tilt of the unstable part accelerated towards the west (T2E) and north (T2N) directions (Fig. 3). The tilt oscillation of high magnitude of the tiltmeter T2 in south-north direction is in connection with the subsidence of about one metre of the unstable part during the winter and in the early spring of 2015. This last period is shown in Fig. 4. The effect of the rising ground water level is obvious. This process is similar to the tilts before the large slump on 12 February 2008 (Újvári et al., 2009).

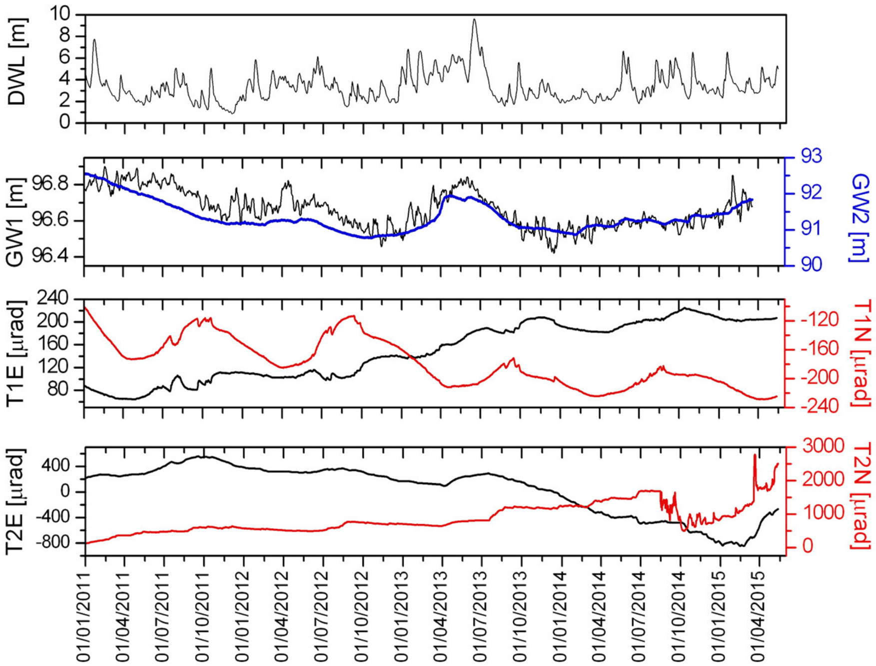

Fig. 3. Data recorded in Dunaszekcső from 1 January 2011 to 19 May 2015. T1E, T1N and T2E, T2N denote the east and north tilt components on the stable and on the unstable (sliding) part of the high bank, respectively. Tilts going in the positive direction mean tilts in the north and east direction and inversely. DWL, GW1 and GW2 denote the water level variation of the River Danube and ground water levels, respectively.

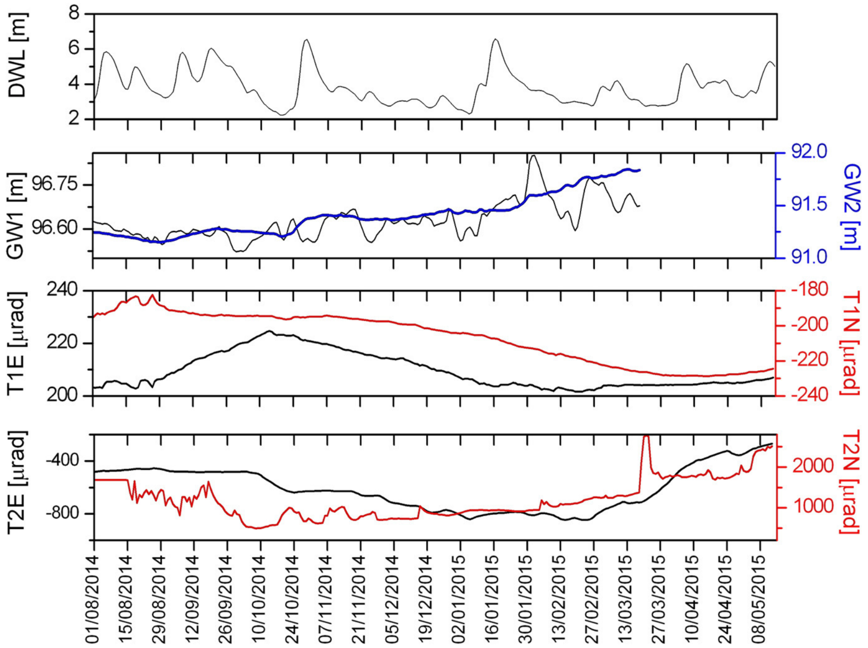

Fig. 4. Data recorded in Dunaszekcső from 1 August 2014 to 19 May 2015. T1E, T1N and T2E, T2N denote the east and north tilt components on the stable and on the unstable (sliding) part of the high bank, respectively. Tilts going in the positive direction mean tilts in the north and east direction and inversely. DWL, GW1 and GW2 denote the water level variation of the River Danube and ground water levels, respectively.

The regression coefficients between tilt components and the water levels and air temperature were separately calculated by multivariable regression analysis for each year from 2011 to 2014. The increasing coefficients in the last two years show the weakening stability of the high bank.

Table 2. Regression coefficients between tilt data and the water level of the River Danube (DWL), the ground water levels (GW1 and GW2) and the air temperature (T). T1E, T1N and T2E, T2N denote the east and north tilt components measured on the top (stable part) and on the unstable (sliding) part of the high bank, respectively. Plus sign denote tilts in the east and north, negative sign in the west and south directions. R2 is the R-square of the adjustment.

Tilt component	Year	Regression coefficients				
		GW1 µrad m^{-1}	GW2 µrad m^{-1}	DWL µrad m^{-1}	T µrad K^{-1}	R^2
T1E	2011	-13	-35	4	-1	0.800
	2012	-41	-44	3	-1	0.658
	2013	-207	33	-2	1	0.484
	2014	-23	63	2	0	0.533
T1N	2011	-193	3	7	0	0.388
	2012	28	-98	-1	1	0.793
	2013	67	-56	1	1	0.619
	2014	0	28	2	0	0.335
T2E	2011	-400	-178	18	4	0.862
	2012	167	95	-8	2	0.373
	2013	369	-83	11	8	0.733
	2014	-156	-1095	15	3	0.859
T2N	2011	185	-287	-16	2	0.965
	2012	33	-512	-6	0	0.933
	2013	-1380	-71	-30	16	0.690
	2014	776	-1198	-22	38	0.531

5. Conclusions

The small regression and correlation coefficients between the water level of the River Danube and tilt components in contrast with the great regression coefficients between the tilt and ground water level mean that the movements of the high bank are mainly governed by the ground water level variations besides the mass loss at the base of the high bank caused by the earth transport of the ground water and the river.

The alternating tilt directions are due to the subsidence sequences during the high bank is searching its new equilibrium position. The increasing tilt amplitudes and regression coefficients could be the precursor of a forthcoming landslide.

Acknowledgements

This work was funded by the Hungarian National Research Fund (OTKA) under project K 81295. Special thanks to Tibor Molnár for his careful maintenance of the instruments, to Ágnes Gimesiné Németh, Ferenc Schlaffer and Frigyes Bánfi for their help in the field works: drilling boreholes, battery changes and reading the data out.

References

1. Applied Geomechanics Inc., 1991. User's Manual No. B-91-1004: 226 Model722 Borehole Tiltmeter. Santa Cruz.
2. Bányai L., Mentes Gy., Újvári G., Kovács M., Czap Z., Gribovszki K., Papp G., 2014. Recurrent landsliding of a high bank at Dunaszekcső, Hungary: Geodetic deformation monitoring and finite element modelling. Geomorphology, 210: 1-13.
3. Casagli, N., Rinaldi, M., Gargini, A., Curini, A., 1999. Pore water pressure and streambank stability: results from a monitoring site on the Sieve River, Italy. Earth Surface Processes and Landforms, 24: 1095-1114.
4. Fabian, M., Kümpel, H.J., 2003. Poroelasticity: observations of anomalous near surface tilt induced by ground water pumping. Journal of Hydrology, 281 (3): 187-205.
5. Kümpel, H.J., Lehmann, K., Fabian, M., Mentes, G., 2001. Point stability at shallow depths: experience from tilt measurements in the Lower Rhine Embayment, Germany, and implications for high-resolution GPS and gravity recordings. Geophysical Journal International, 146: 699-713.
6. Mentes, G., 2003. Monitoring local geodynamical movements and deformations by borehole tiltmeters in Hungary. In: Proceedings of the 11th FIG Symposium on Deformation Measurements, S.C. Stiros and S. Pytharouli (eds.), Santorini, Greece, 43-50.
7. Mentes G., 2004. Investigation of the stability of borehole tiltmeters working in unpacked boreholes inundated with ground water. Acta Geodaetica et Geophysica Hungarica, 39 (1): 49-54.
8. Mentes, G., Theilen-Willige, B., Papp, G., Síkhegyi, F., Újvári, G., 2009. Investigation of the relationship between subsurface structures and mass movements of the high loess bank along the River Danube in Hungary, Journal of Geodynamics, 47: 130-141.
9. Mentes, G., 2012. A new borehole wire extensometer with high accuracy and stability for observation of local geodynamic processes. Review of Scientific Instruments, 83: 015109
10. Rinaldi, M., Casagli, N., Dapporto, S., Gargini, A., 2004. Monitoring and modelling of pore water pressure changes and riverbank stability during flow events. Earth Surface Processes and Landforms, 29: 237-254.
11. Simon, A., Curini, A., Darby, S.E., Langendoen, E.J., 2000. Bank and near-bank processes in an incised channel. Geomorphology, 35: 193-217.
12. Terlien, T.J.M., 1997. Hydrological landslide triggering in ash-covered slopes of Manizales (Columbia). Geomorfology, 20: 165-175.
13. Újvári, G., Mentes, Gy., Bányai L., Kraft, J., Gyimóthy, A. Kovács, J., 2009. Evolution of a bank failure along the River Danube at Dunaszekcső, Hungary. Geomorphology, 109: 197-209.